Capturing Uncertainty in the Common Tactical-Environmental Picture

Presented by
Bob Miyamoto (APL-UW)
for
APL-UW
ARL-UT
NRL-SSC
OSU
METRON

People

QuickTime™ and a
GIF decompressor
are needed to see this picture.

QuickTime™ and a
GIF decompressor
are needed to see this picture.

Organization	POC	Area
APL-UW	Robert Miyamoto, 206 685 1303, rtm@apl.washington.edu Jim Pitton, 206 543 1366, pitton@apl.washington.edu Robert Odom, 206 685 3788, odom@apl.washington.edu Darrel Jackson, 206 543 1359, drj@apl.washington.edu	Acoustic modeling, bottom modeling, inversion, statistics, and sensitivity
NRL-SSC	Pat Gallacher, 228 688 4798, Gallacher@nrlssc.navy.mil Dan Fox, 228 688 5588, fox@vulcan.nrlssc.navy.mil Jim Fulford, fulford@nrlssc.navy.mil	Dynamic Ocean Modeling Assimilation Geoacoustics
Oregon State	Murray Levine, 541 737 3047, levine@oce.orst.edu	Internal Waves
ARL-UT	Brian La Cour, 512 835 3961, blacour@arlut.utexas.edu Karl Fisher, 512 835 3603, Kfisher@arlut.utexas.edu	Active signal and information processing
METRON	Larry Stone, 703 787 8700, stone@metsci.com	Data fusion/tracking
NAVOCEANO	Captain Tim McGee, McGeeT@navo.navy.mil	Environmental Uncertainty

Goals

- Use <u>existing</u> science to characterize and represent the uncertainty in the tactical and environmental picture due to uncertainty about environmental features that affect acoustic detection and classification of threats.
- Improve prosecution of threats

Focus on active acoustic sensors

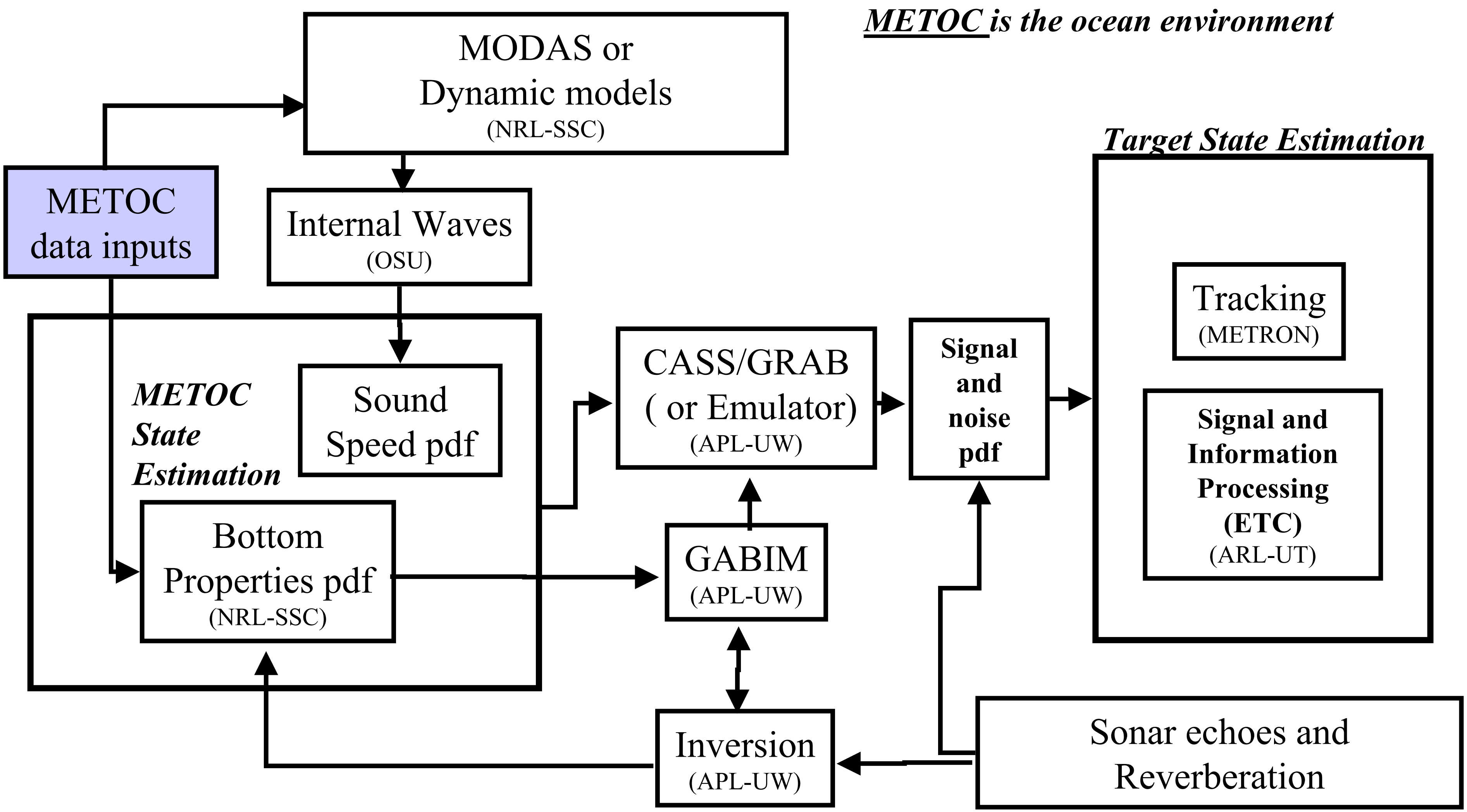
Overview

- Provide:
  - measures or estimates of the uncertainty in environmental parameters relating to the ocean and bottom;
  - methods of efficiently propagating this uncertainty through acoustical models;
  - methods for estimating and representing the effect of environmental uncertainty on estimates of tactical quantities such as target state.
  - tools for computing and mitigating the resultant uncertainty at all levels of the process.

Key Questions

- How to merge ocean circulation with internal waves to generate sound speed distributions
  - Role of dynamic ocean models
- How to characterize bottom uncertainty?
- How to propagate uncertainty through an active acoustic model to improve state estimation of a target?
- Can we compute and represent the uncertainty in estimation of target state variables resulting from environmental uncertainty?

Notional Architecture

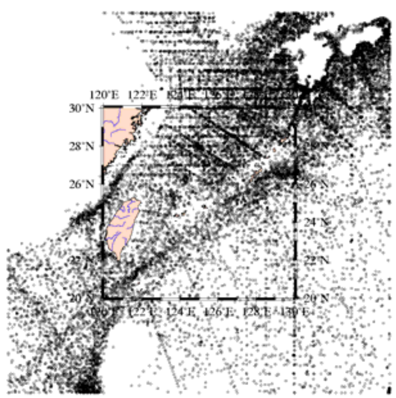


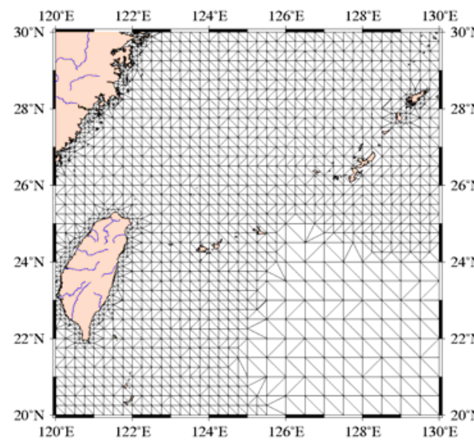
Modular Oceanographic Data Assimilation System (MODAS)

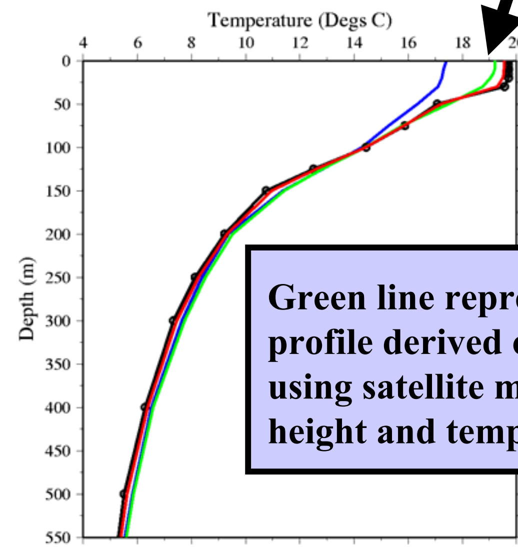
MOODS Profiles

MODAS Climatology

Satellite Measured SSH and SST







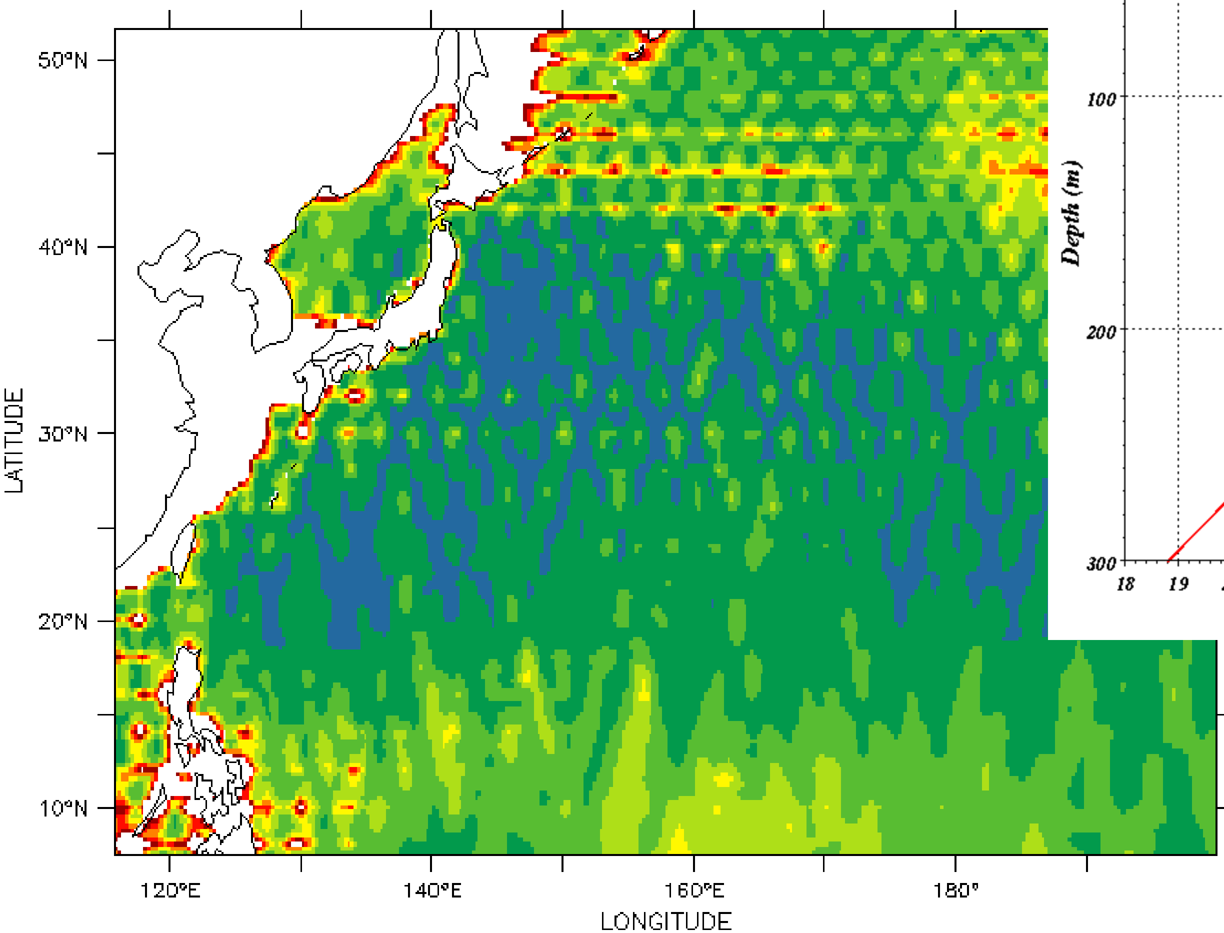
Green line represents profile derived only using satellite measured height and temperature

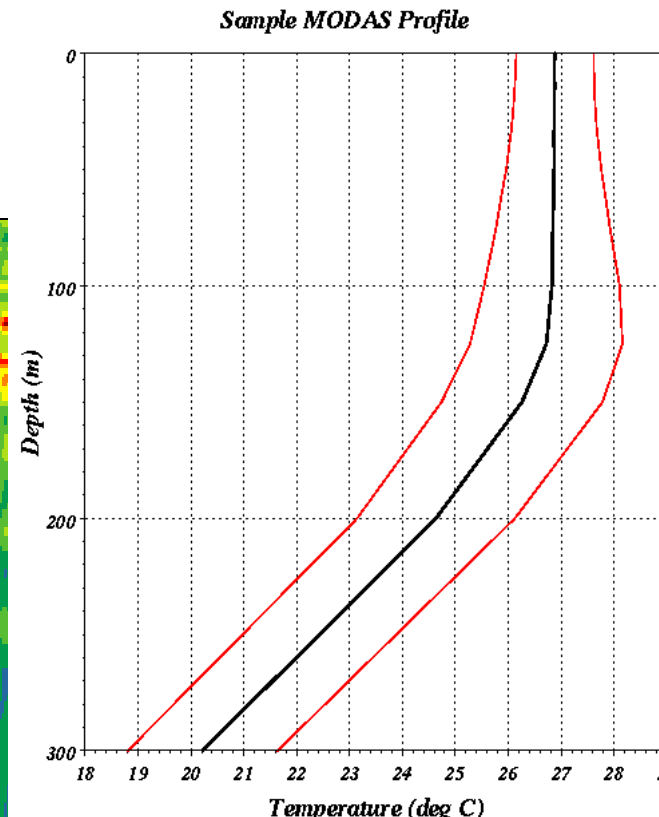
Climatology
MODAS Synthetic
Final Analysis
In Situ BT

Decades of edited MOODS profiles are used to derive statistical relationships between surface height and temperature and subsurface temperature and salinity

Relationships are stored on an irregular mesh, varying from 1 to 1/8 degree in resolution to permit high resolution analyses in shallow water regions

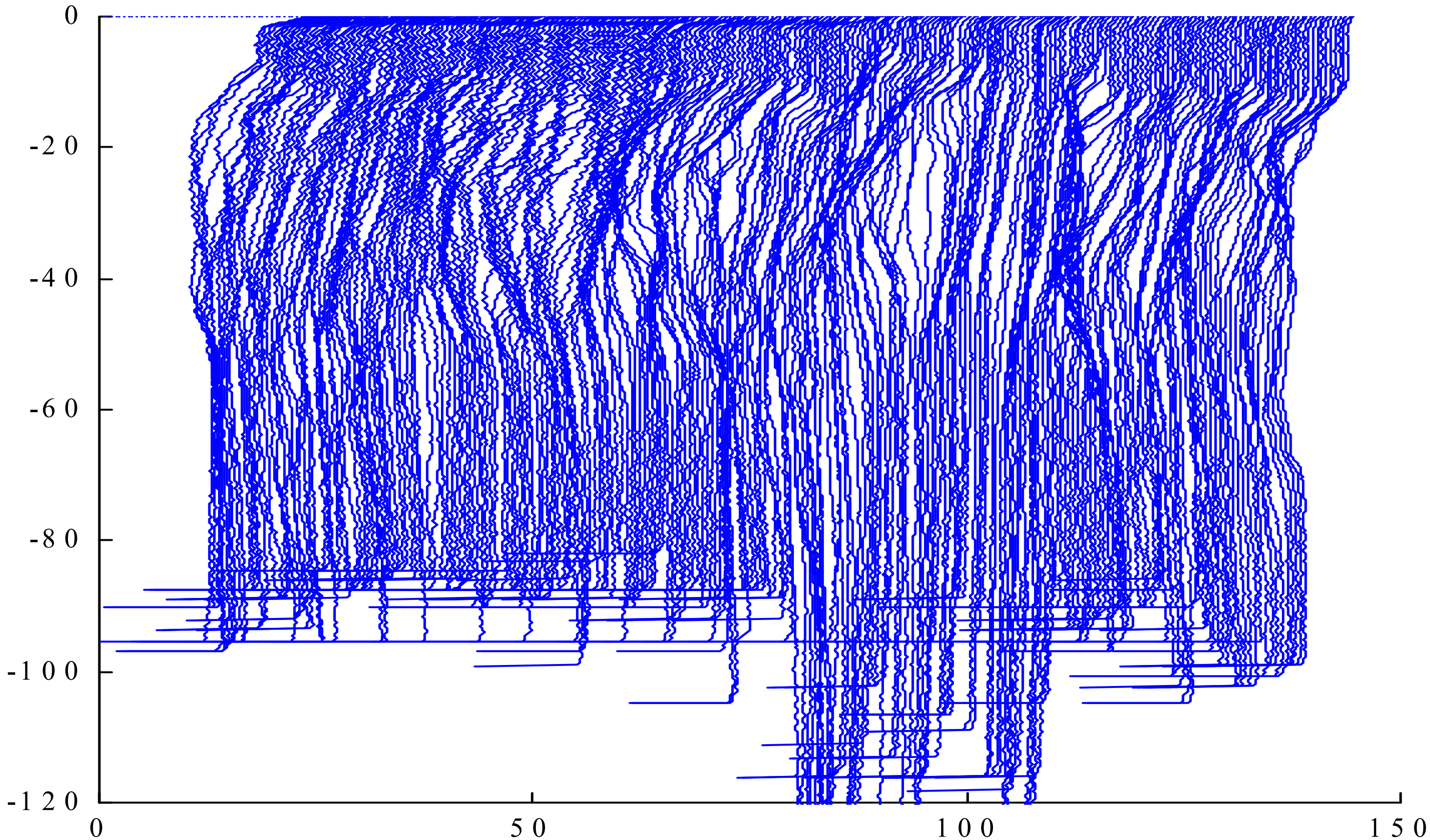
MODAS Uncertainty





Real sound speed

- Variance vs depth does not capture the proper vertical, spatial and temporal coherence



Dynamic oceanography

- Hydrostatic (NCOM) Model
  - Produces realistic T and S fields for small to moderate amplitude internal waves and other small aspect ratio features
  - Uses realistic coastlines and bathymetries
    - Simulations of the Chesapeake Bay and adjoining shelf
    - MidAtlantic Bight
    - East China Sea
- Nonhydrostatic models
  - Lamb and U. of Hamburg 2D and Smolarkiewicz 3D
  - Produces realistic T and S fields for moderate to large amplitude internal waves and other large aspect ratio features
  - Uses simplified coastlines and bathymetries (at present)
    - Simulations of Yellow Sea
    - Primer area in MidAtlantic Bight
    - Strait of Messina

Internal Waves

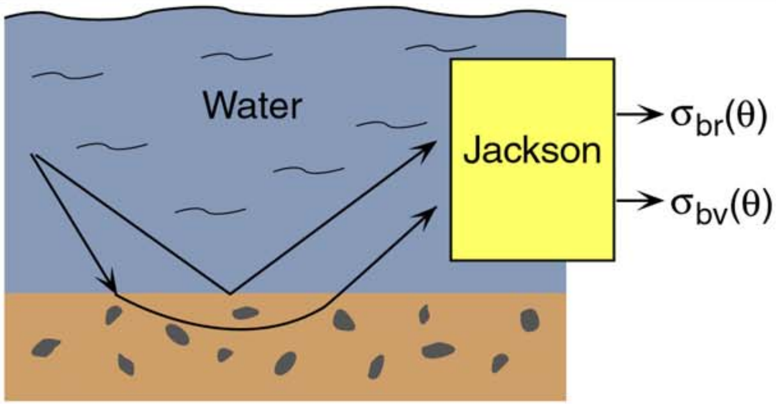
- Estimate average ***N*** (vertical density gradient) and its uncertainty from the MODAS and/or dynamic model T and S fields.
  - Note: depth dependence of ***N(z)*** determines the vertical structure (vertical mode shapes), and magnitude of N determines the energy level and frequency range
  - Average ***N(z)***
    - Initially assume horizontally uniform
    - Use MODAS and/or dynamic model mean T&S
  - Uncertainty in ***N(z)***
    - Estimate uncertainty in both magnitude and depth dependence
    - Use MODAS and/or dynamic model to estimate statistics of T&S and mixed layer depth
    - Estimate uncertainty by having assumed horizontal uniformity
  - …….

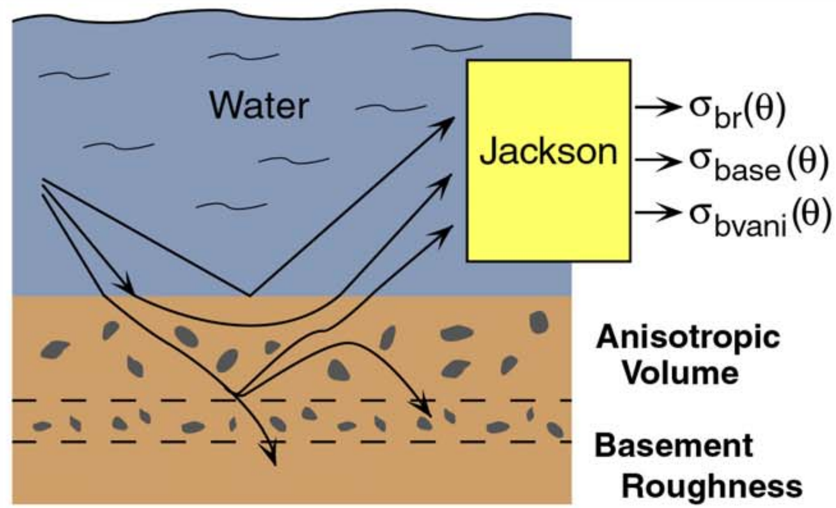
Internal Waves

- Determine Internal Wave Spectrum
  - Continuum frequency
    - Begin with the continuum wavefield using modified Garett-Munk like model
    - Use model modal distribution and anisotropy
  - Internal tide
    - Sometimes important
    - No model available, but could apply some ad hoc parameterization
  - High frequency wave packets
    - Sometimes important
    - No model available, but could apply some ad hoc parameterization
- Combine the estimates of N and its uncertainty with internal wave variability
  - Produce vertical displacement field as a random process using internal wave spectrum and uncertainty in N
  - Use vertical displacement field with MODAS and/or dynamic model mean sound speed profiles c(z) and its uncertainty to specify a random c(z,t) for use by acousticians.

Geophysical-Acoustic Bottom Interaction Model (GABIM)

Jackson et al. (1994), Mourad & Jackson (1993)	GABIM (2000)





- Simple gradient sound speed seafloor model
- Exact analytical solution (Airy function)

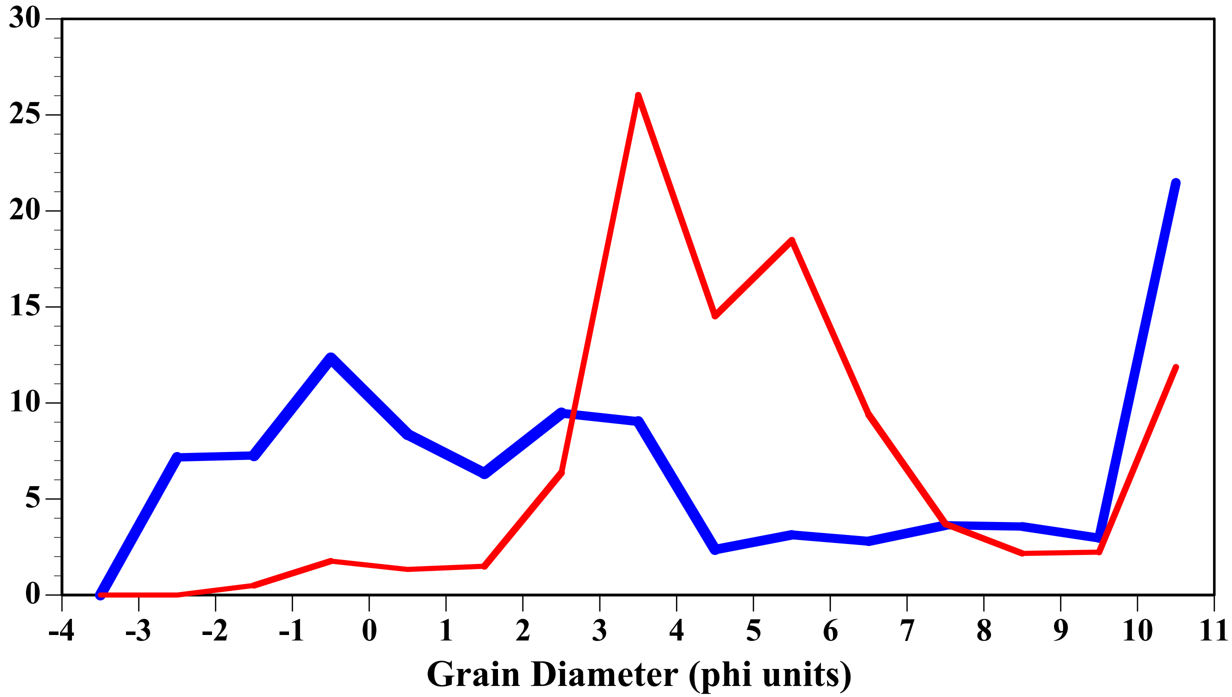
- SAFARI bottom propagation kernel (Schmidt, 1988)
  - arbitrary bottom structure
  - shear waves, transverse isotropy if necessary
  - fast, accurate numerical implementation

Characterize bottom uncertainty

Symbol	Definition	Short Name
f	Frequency of sound in water (Hz)	Frequency
C_1	Water sound speed (m/s) at the water/sediment interface	Water sound Speed
$\rho(Z)$	Ratio of sediment mass density to water mass density	Density Ratio profile
$\nu(Z)$	Ratio of sediment sound speed to water sound speed	Sound speed ratio profile
$\delta(Z)$	Ratio of imaginary wavenumber to real wavenumber for the sediment	Loss parameter profile
$\sigma_2(Z)^*$	Ratio of sediment volume scattering cross section to sediment attenuation coefficient	Volume parameter profile
γ_2	Exponent of sediment relief spectrum of the water/sediment interface	Sediment Spectral exponent
ω_2	Strength of sediment relief spectrum (m^4) of the water/sediment interface at wavenumber $2\pi/\lambda = 1\ \mu^{-1}$	Sediment Spectral strength

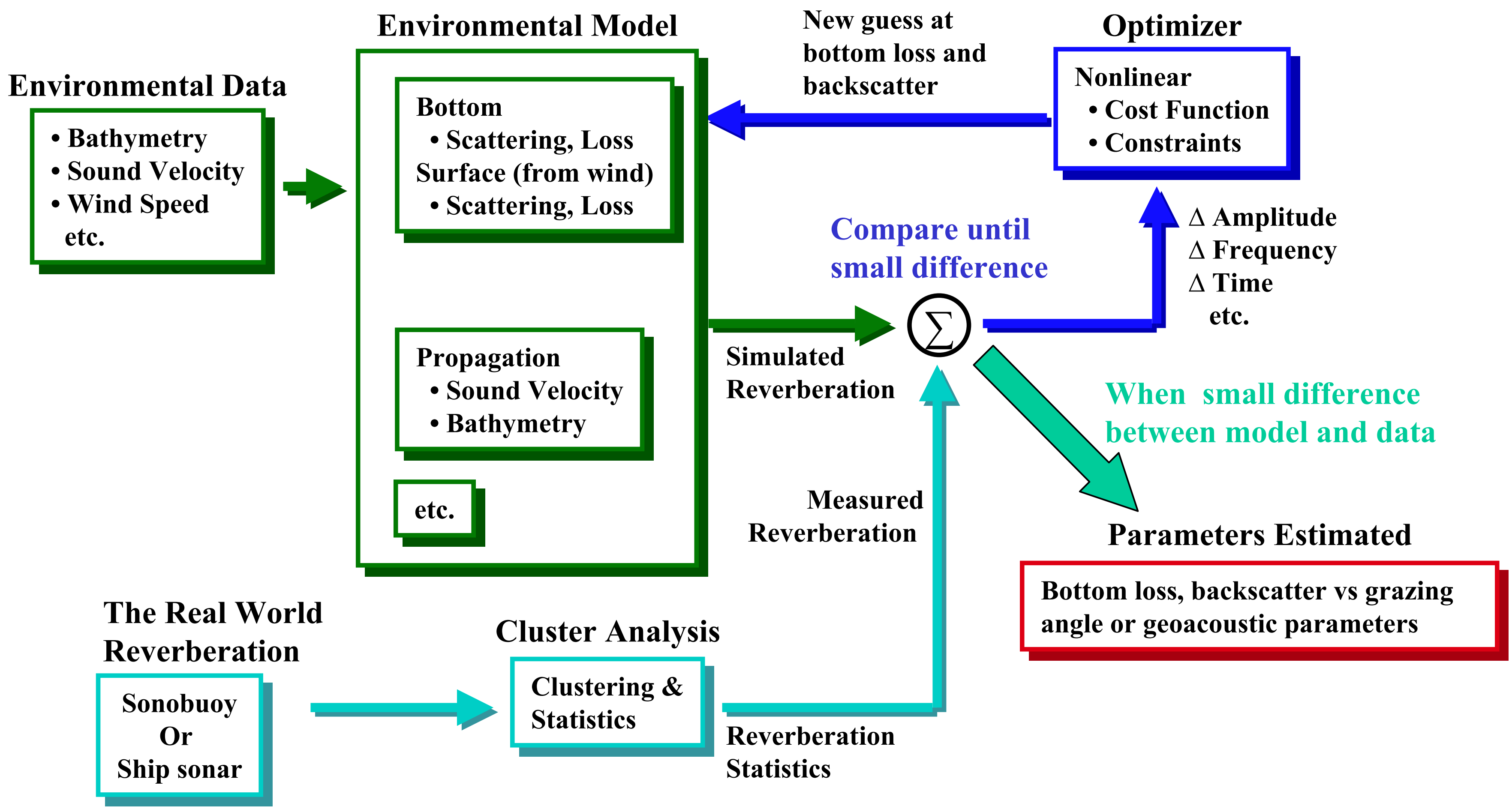
*** In the cases where anisotropic volume scattering is required, σ_2 is replaced by optional values.**

Bottom characterization

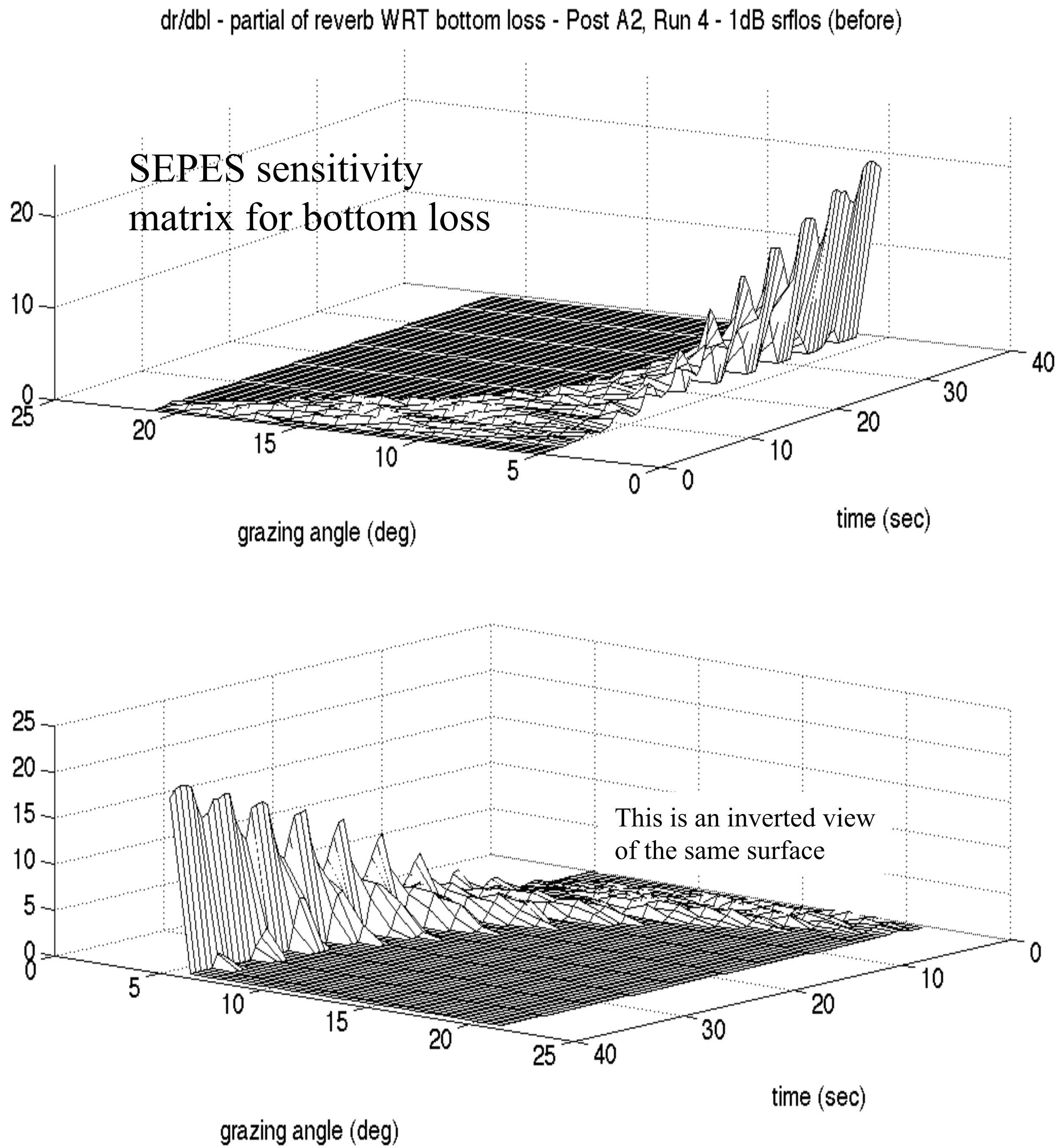


Each curve has a mean grain size of 5.3 - surface reflectivity, porosity, and permeability are significantly different.

Inverting for bottom parameters



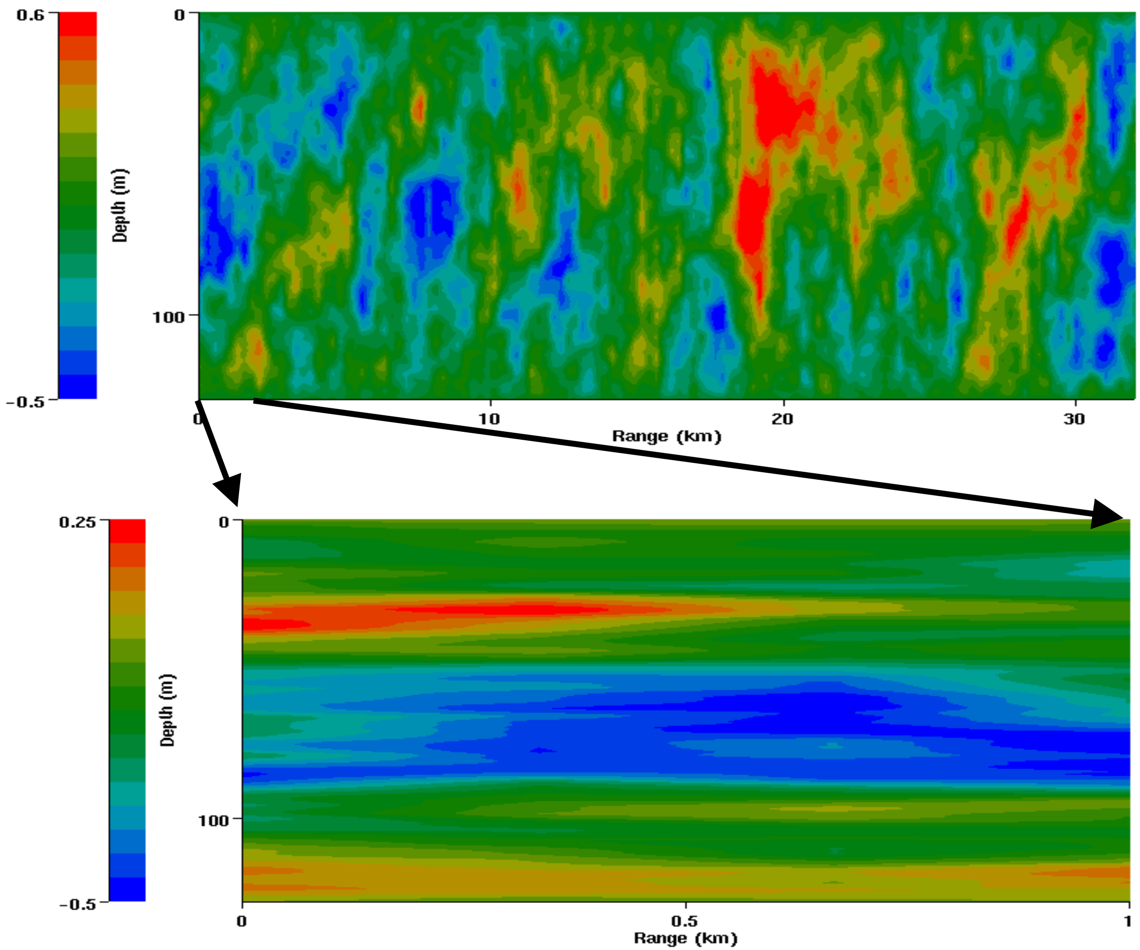
SEPES sensitivity matrix for bottom loss



This is an inverted view of the same surface

Acoustic Modeling

Internal wave displacement field



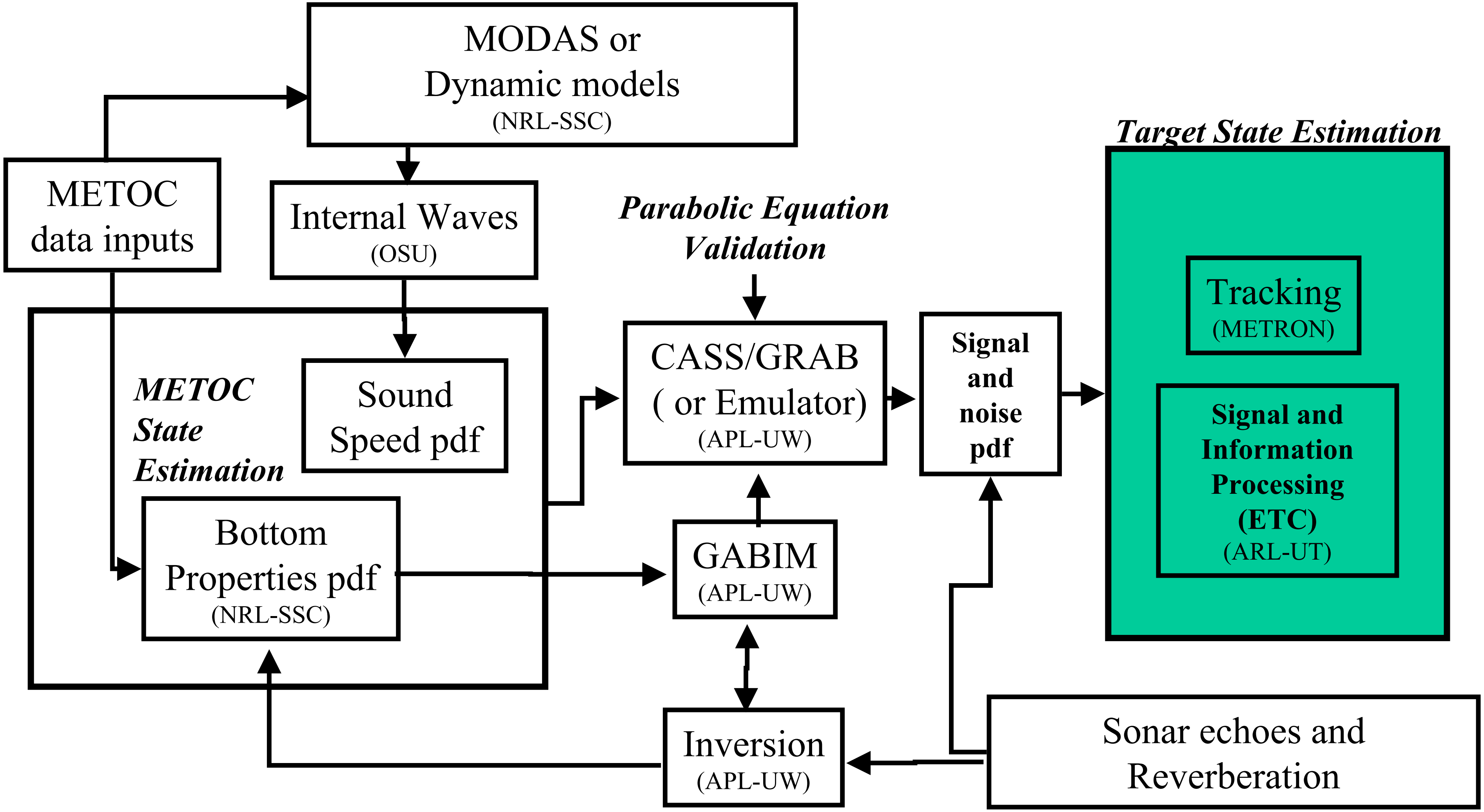
Large scale ocean
+
Internal Waves

6 kHz
acoustic field

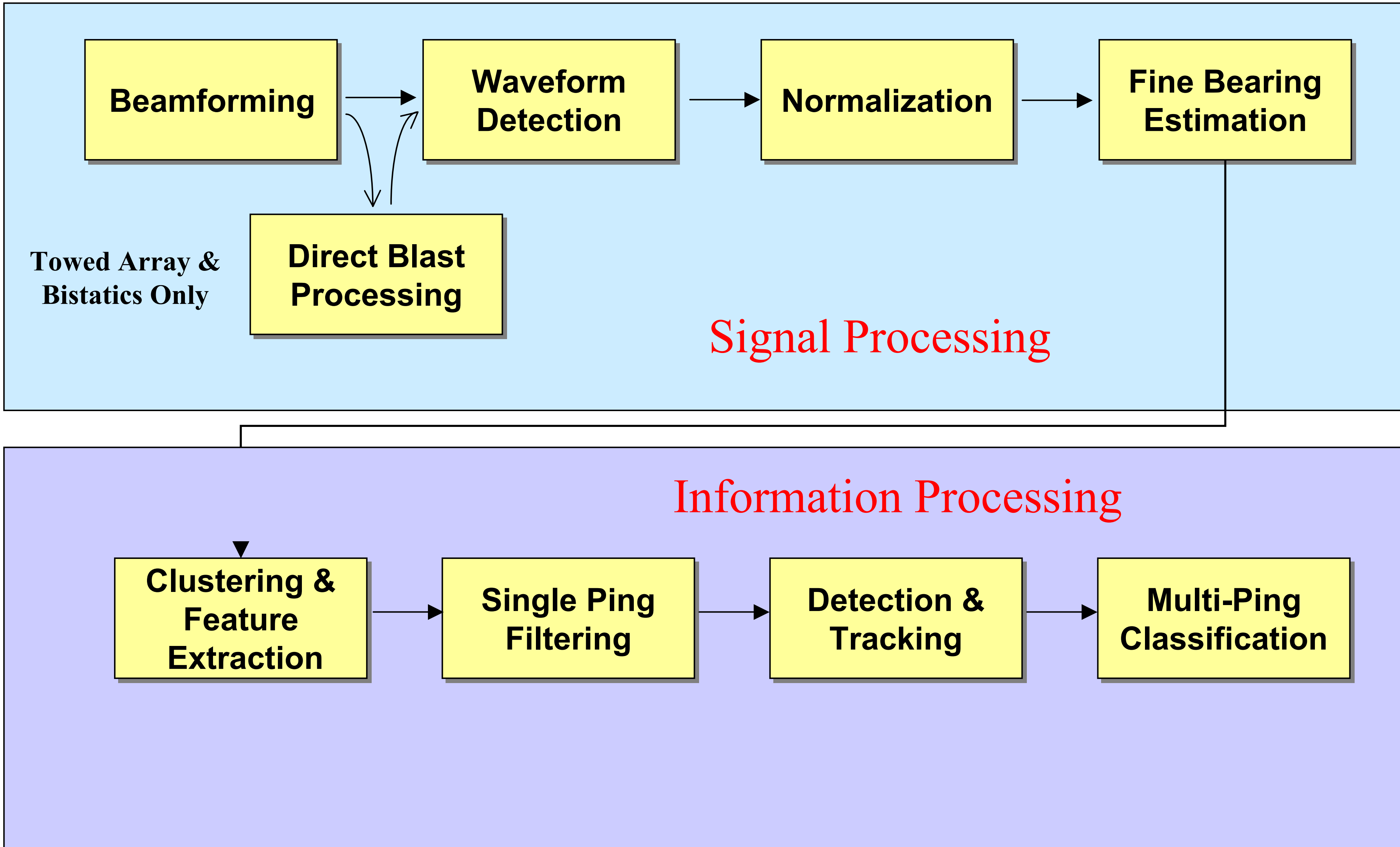
Acoustic modeling with uncertainty

- Begin with PDFs with PE
- Compare with CASS/GRAB
  - Gaussian Ray Bundle propagation, active model
- Brute force Monte-Carlo calculation
  - 8 networked PCs
- More efficient calculations to generate acoustic PDFs
  - Importance Sampling
  - Interpolation: complicated multivariate distributions can be constructed (estimated) using local approximations.
    - Gaussian mixture distributions
    - Neural Nets based on Monte Carlo
      - Sensitivity of inputs to outputs is a useful attribute

Notional Architecture



Echo Tracker Classifier



Improving DCL via ETC

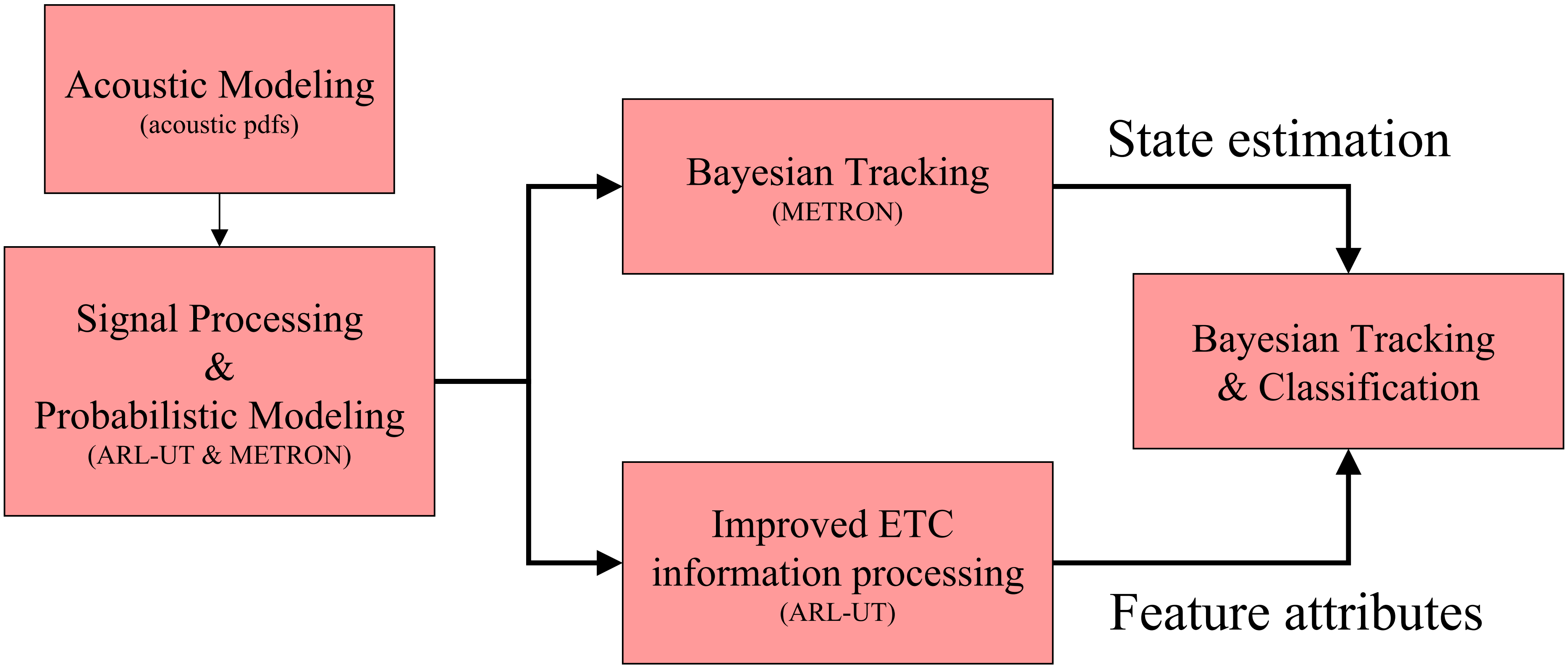
Why ETC?

- ETC is the baseline standard for automated detection, classification, and localization in active sonar ASW.
- Thus, improvements in DCL for ETC may serve as a transition to and integration with existing 6.3 efforts

How will Capturing Uncertainty Improve ETC?

- Through acoustic modeling, we can understand how aspects of the environment impact performance.
- Allows for environmental conditioning of DCL algorithms.
- Likelihood functions may be incorporated to improve fine bearing estimation, clustering, and tracking.

Parallel tracks of development



Signal Generation

Acoustic Modeling
(acoustic pdfs)

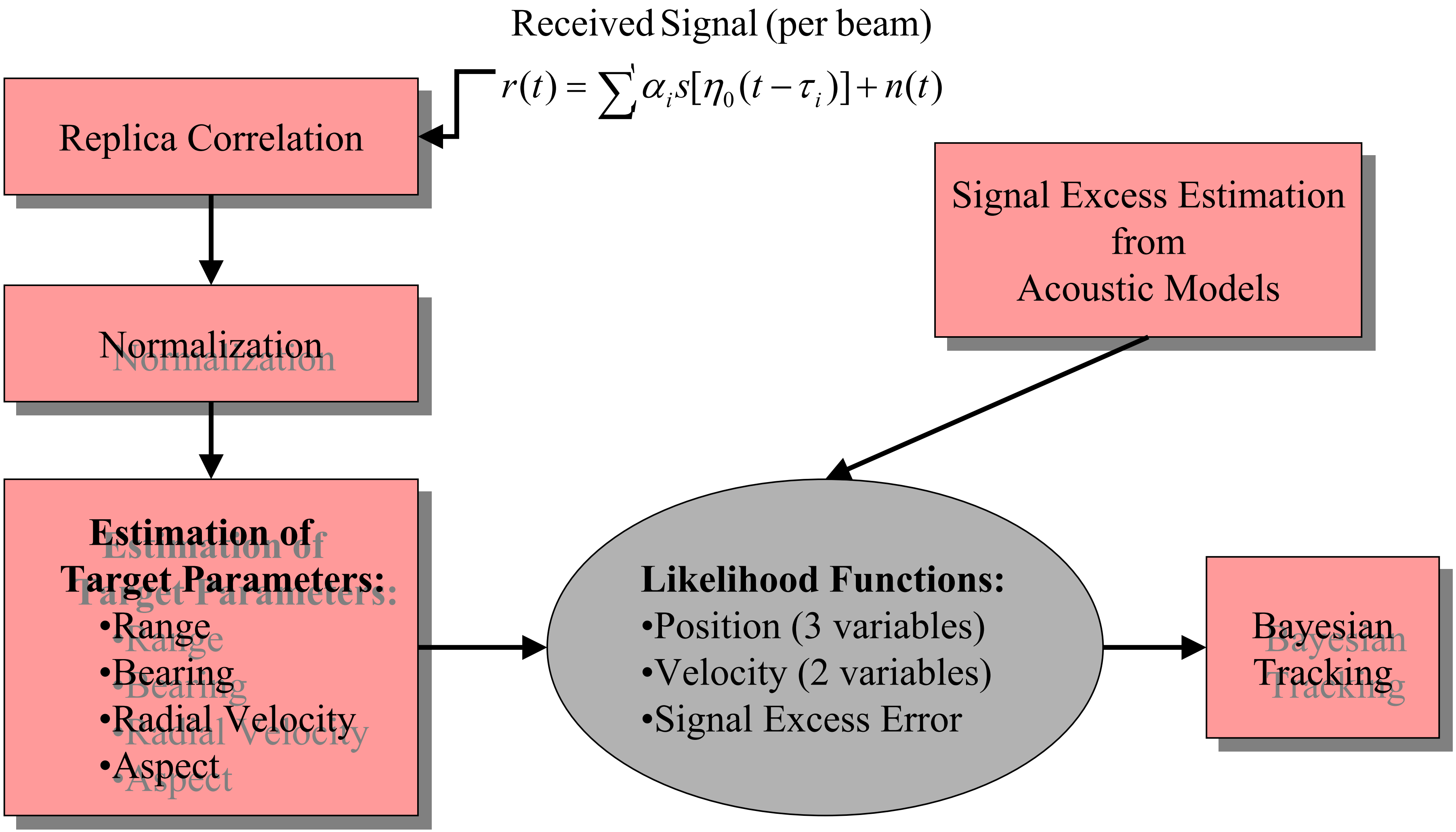
Signal Excess PDF
Over Location, Frequency, and Multipaths:
- Transmission Loss
- Reverberation Loss
- Transit Time
- Source & Receiver Angles

- Select ownship, target information
- Determine target impulse response
- Select transmission source *s(t)*
- Generate noise *n(t)*
- Determine beam patterns

Received Signal (per beam)

$$r(t) = \sum_i \alpha_i s[\eta_0 (t - \tau_i)] + n(t)$$

Target State Estimation



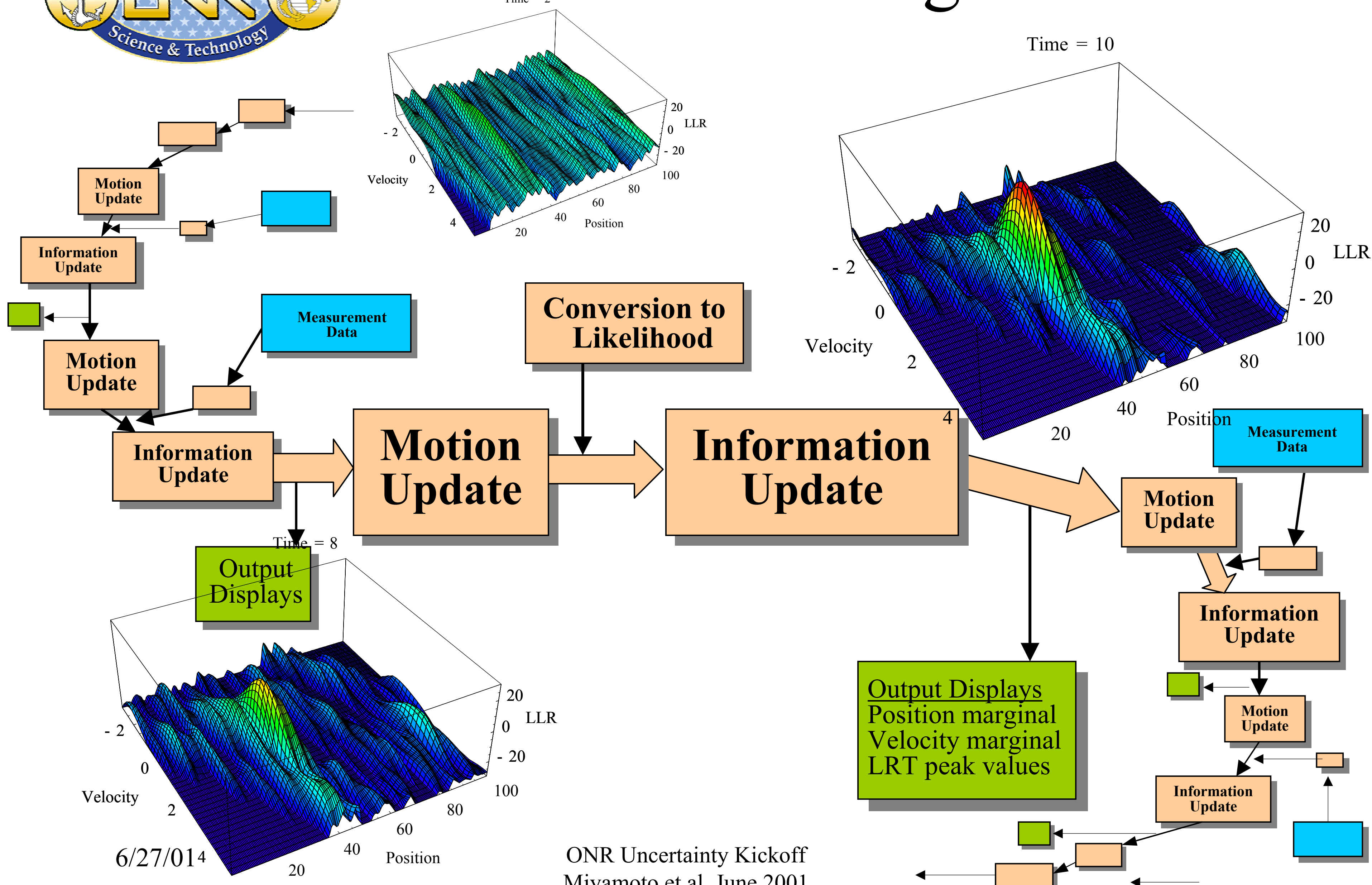
Likelihood Ratio Tracker

- Work with ARL/UT to identify and define the likelihood functions from the Echo Tracker Classifier (ETC)
  - Estimated range of contact
  - Estimated bearing
  - Observed SNR.
  - the error in the signal excess estimate
    - from target state (position and velocity) to the sensor
- Design an LRT to use the likelihood functions
  - Add another state variable - error in the signal excess estimate
- Develop methods of calculating and displaying the effect of uncertainty (SE) on the estimate of target state produced by the LRT

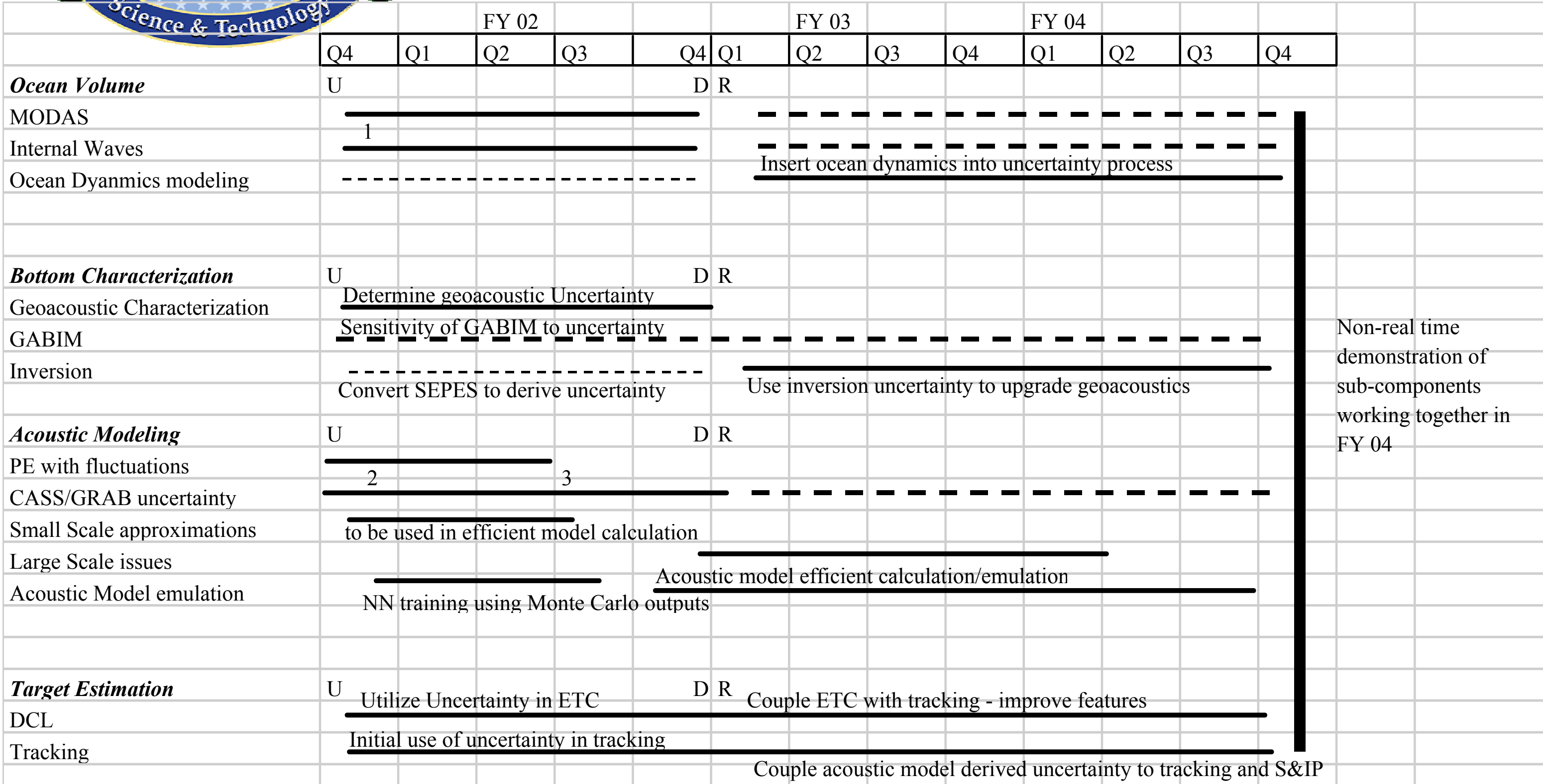
Likelihood Ratio Tracker

- LRT is a discrete non-linear Bayesian track-before-detect system for processing sensor responses to determine the presence and state of a target
- Using likelihood functions to represent sensor information LRT integrates these responses over time and space to increase detection probability without increasing false alarm rate
- LRT is capable of tracking multiple targets

LRT Processing Flow



Schedule



Notes:

U = define initial Uncertainty interfaces

D = initial demonstrations (in specific area such as New England Coast)of uncertainty couplings.

R = refine Uncertainty interfaces based on sub-component examples at end of FY 02

1) Couple the ocean mean sound speed and error to internal wave fields
2) Compare CASS/GRAB acoustic fluctuations due to internal waves with existing PE calculated fluctuations
3) Begin Monte-Carlo calculations of active sonar with METOC probability distributions

Insert ocean impulse response uncertainty

Transitions

- ONR 6.3 FNC on Uncertainty
- NAVOCEANO
- SPAWAR PMW 155
- PEO(MUW)/PMS 411
- PEO(A)/PMA 264

Summary

- 6.2 team will be exploring characterization and application of uncertainty
  - Multidisciplinary team
  - Strong transitions
- Project is focused on key issues
  - Transition to system application in future

Key Questions

- How can we merge uncertainty in large-scale circulation with the uncertainty created by internal waves to generate a distribution of sound speed profiles? What is the value of a dynamic model versus a statistical approach? What is the contribution of internal waves to uncertainty and how many modes are needed?
- How we can characterize uncertainty in the ocean bottom sediments either through historical data or acoustic inversion techniques that can be used to generate a distribution of local bottom conditions?
- Given uncertainty of the ocean sound speed and the bottom can we develop techniques to efficiently propagate the uncertainty through active acoustic models to components (e.g., transmission loss, arrival structure, interference) that can be used for tactically relevant (i.e., real-time) state estimation of undersea targets?
- How does the fidelity of the model impact uncertainty?
- Can we compute and represent the uncertainty in estimation of target state variables (e.g., position, speed, and classification) resulting from environmental uncertainty?